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Suspended Sediment Sampling

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ABSTRACT: Fine sediment (< 2mm) is of considerable importance in fluvial systems given the physical and ecological impacts caused by elevated levels. Fine sediment is eroded from the landscape and subsequently transported in suspension by rivers and streams. Suspended sediment can be sampled using a range of manual and automated approaches designed to estimate river loads and capture samples for subsequent analysis. The most appropriate method(s) for adoption will be determined by the flow and sediment dynamics, sample/data requirements and resources available. This section presents information on a range of approaches for the direct sampling of suspended sediment in fluvial systems, discussing the advantages and disadvantages of each.

KEYWORDS: fluvial, depth-integrated, single-point, passive, time-integrating, suspended sediment sampling

Introduction

In many river systems, fine material is transported in suspension and is termed the suspended sediment load (Owens *et al.,* 2005). The fine fraction incorporates both the organic (e.g. plankton and detritus) and mineral particles (e.g. sand and silt) of diameters > 0.45 μm and < 2000 μm. Particles within this range account for the majority of material eroded from the landscape and subsequently transported by rivers and streams (Meade *et al.*, 1990). The lower boundary (0.45 μm) traditionally provides the distinction between dissolved and solid material and is somewhat of an arbitrary guideline as defined by analytical procedures (Håkanson, 2008). The upper boundary represents the transition between material typically transported close to the river bed (bed-load) and the material carried in suspension (suspended-load) (Owens, 2008). An additional distinction may also be made between fine sediment and very-fine sediment (< 62.5 μm). The latter is not controlled by the hydraulic characteristics of flow; rather its occurrence is dependent on the upstream supply rate (Khullar *et al.*, 2010). This is commonly termed the 'wash load' and constitutes an important component of the particulate flux from terrestrial surfaces (Owens, 2008). This material may flocculate to produce much larger composite particles and can be extremely important in the transfer of pollutants and the degradation of water-bodies (Droppo, 2001, Ongley*, et al.*, 1992).

Factors influencing the optimal sampling approach

A wide range of techniques are available for sampling suspended sediment in rivers. The appropriateness of each technique is determined by the flow and sediment dynamics; sample and data requirements; and resources available. These factors will determine the sampling approach adopted and the way in which the sample is handled (transported and stored) following collection. It may therefore be pertinent to give careful consideration to the following question prior to deployment: *Given the inherent temporal variability of suspended sediment flux, cross-sectional variations in sediment transport and the mass of material required for subsequent analysis, what approaches will provide the most representative sampling method?* The sampling techniques described herein can be broadly classified as: (i) manual and, (ii) automatic.

Manual sampling

The most effective and direct means of obtaining a suspended sediment sample is through manual sampling of the river. This is considered the standard against which the accuracy of automated and indirect approaches are compared (Wren *et al.*, 2000). This is often the adopted approach for regulatory assessments, including the General Quality Assessments conducted by the Environment Agency. However, the following points relating to manual sampling should be considered: (1) safe access during high-flows must be guaranteed; (2) financial and time constraints associated with travel to and from the site may limit site visit frequency; and (3) important storm flows are infrequent and often difficult to predict. Given these constraints, it is difficult to attain continuity of high temporal resolution sampling and capture infrequent high-magnitude events using this approach in isolation. Although, this approach is often used in conjunction with automated approaches (see Automated Sampling section). The operational guidelines for manual sampling are specific to the sampling apparatus used, a range of which are now discussed in the following sections.

Depth-Integrated

Given the vertical and horizontal variability of suspended sediment concentrations (SSCs) that often exist in rivers transporting particles > 63 µm in diameter, it is recommended that depth-integrated sampling should be undertaken to ensure a representative sample is collected (Horowitz *et al.*, 1990, Wass and Leeks, 1999). This may be achieved using depth-integrated samplers (such as the D-77 or DH-81), whereby a single discharge-weighted composite sample is collected by moving the sampling device through the stream vertical (Vanoni, 2006). This method is capable of providing vertically representative samples when the sampler is lowered to the stream bed and raised at a uniform rate. Most depth-integrated samplers were developed as part of the US Federal Interagency Sedimentation Project (FISP) and are capable of collecting samples ranging from 0.57 – 6.0 litres in volume. However, several factors limit their deployment including absolute minimum operating depths ranging from 0.08 – 0.24 m, a maximum operating depth of 4.5 m for rigid bottle samplers and a minimum velocity of 0.45 m s^{-1} to ensure isokinetic sampling (cf. Davis, 2005).

Alternatively, samples may be acquired using point-integrating samplers (e.g. P-46, P-61 or P-72). These provide discrete representative samples of suspended sediment at the measured point. The basis of this approach is that a sufficient number of individual point samples are collected to determine the average value of the property of interest (e.g. SSC – typically reported in mg L^{-1}). Alternatively, when point samples and corresponding point velocities are integrated, it is possible to calculate the flux (total mass transported per unit time) of suspended solids, or bound constituents (Meade and Stevens Jr, 1990). Point-integrating devices are the preferred apparatus when sampling deep rivers (i.e. > 4.5 m). However, their deployment is restricted by the hydraulic characteristics of the flow, absolute minimum sampling depths of 0.11 – 0.15 m and a limited sampling capacity of 0.57 or 1.14 L, which may be insufficient for some applications (cf. Davis, 2005).

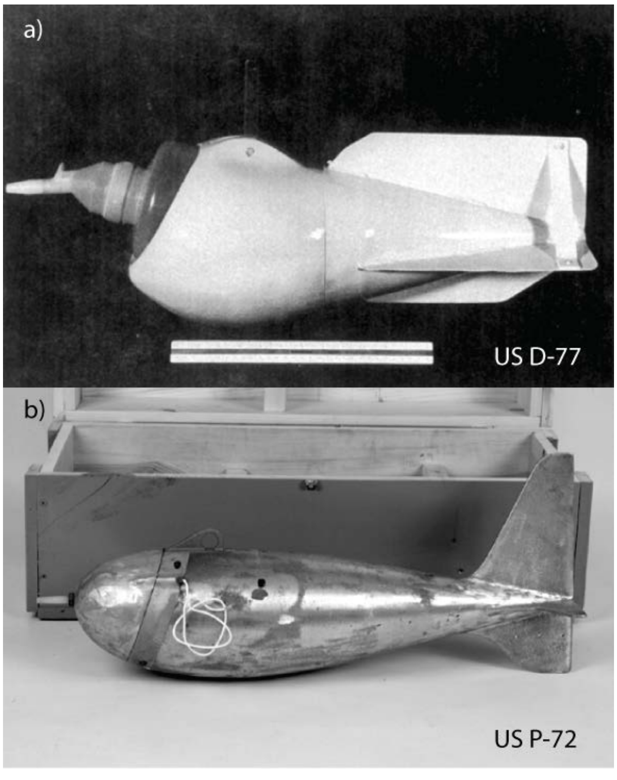

Figure 1: Examples of a) depth-integrating and b) point-integrating suspended sediment samplers designed through the US Federal Interagency Sedimentation Project (FISP). (Modified from www.rickly.com).

To account for horizontal variations in suspended sediment, multiple vertical sampling profiles should be conducted across the channel. An absolute minimum of four verticals is required. There are two commonly adopted approaches for calculating the required number: (1) equal discharge increment (EDI); or (2) equal width increment (EWI). Detailed descriptions of these are provided in Gray *et al*. (2008: available online).

Single-point

Whilst it is best practise to sample across the flow cross-section, it is acknowledged that this may not always be feasible, especially when the river is in spate (Abtew and Powell, 2004). Assessments have therefore been conducted on the representativeness of single-point samples. It has been observed that single representative samples can be obtained in shallow, well mixed streams where suspended sediment is uniformly distributed along the vertical and horizontal planes (Sheldon, 1994). This is achieved by positioning the sampler intake at 60% of the stream depth (Newburn, 1988). However, to ensure representativeness of the single-point sample, *a priori* measurements should be made at more than 10 locations (determined using the aforementioned EWI method) through the cross-section to determine the relation between the average and the point at which sampling is to be undertaken. A coefficient can then be produced to convert future discrete samples to the mean cross-sectional value (Horowitz, 1995). Alternatively, this information can be used to determine the optimal location for sampling (Porterfield, 1977). However, it should also be acknowledged that the relation between the average and the point at which sampling is undertaken and therefore the optimal location may not be constant, becoming modified with changes in bed forms, source and type of sediment.

Automated Sampling

An alternative to manually sampling the river is to deploy apparatus capable of automatically collecting a sample without a field operator being present. This is possible using basic passive samplers, more advanced pump samplers, or time-integrating sampling devices. Each is assessed in the following sections.

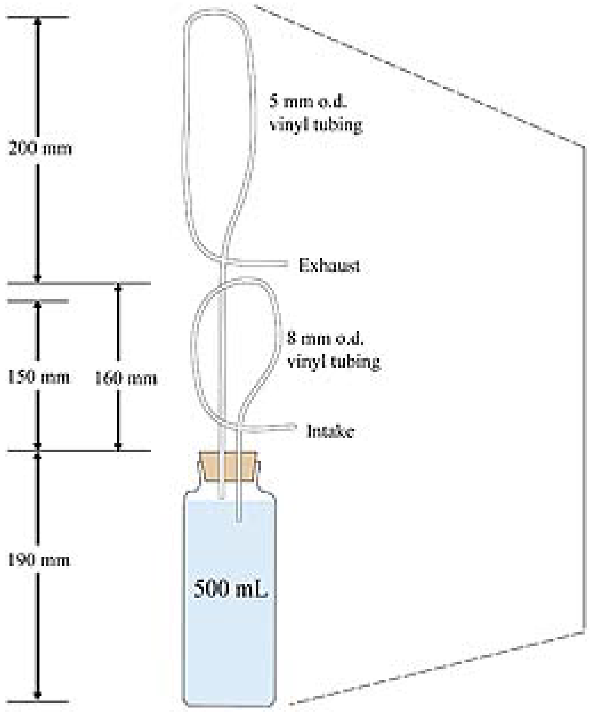

Figure 2: Siphon sampler (modified after Graczyk et al. 2000)

Passive

The single-stage sampler (FISP, 1961), also known as a siphon sampler, is an example of a passive sampling device which is fixed at the stage height at which the sample will be taken. Water enters the intake tube as the river level rises. The sample then enters the sampler body upon the creation of a siphon when the water level exceeds the height of the intake tube loop (Figure 2). An airlock is created when the water level in the bottle reaches the exhaust tube, preventing further filling (Mackay and Taylor, 2012). These devices may be staggered vertically at a single point in the channel (e.g. Estrany *et al.*, 2009b), or along a cross-section (e.g. Shellberg *et al.*, 2013). Single-stage samplers may be useful in capturing material for SSC determination (e.g. Estrany *et al.* 2009a, Estrany *et al.* 2009b) and determination of particle size characteristics (e.g. Kostaschuk *et al.* 2003) especially in remote locations. These devices have been reported to produce representative samples in small streams (Collins, 1981) although trials in large rivers have reported differences between manual and single-stage sampling in the region of 10 - 20% for SSCs (Batalla, 1993). Modifications to the original rising-stage sampler have enabled sampling of the falling-stage; secondary rises and; the collection of sufficient material for geochemical analysis (e.g. Minella *et al.* 2009).

Automated Pump

The collection of suspended sediment samples has been made significantly easier in recent years following the commercial availability of automatic pump samplers. These consist of an intake, sample distributor, pump, bottle container unit and activation system (Gray *et al.* 2008), whereby a sample volume is drawn up from the channel through the creation of a partial vacuum (Newburn, 1988). These samplers have become efficient, lightweight, affordable, and computer controlled, allowing sampling to be triggered remotely (e.g. via SMS) or by external trigger devices (e.g. in response to changes in river flow). This remote activation has enabled greater precision and frequency of sampling during storm events. Most pump sampling equipment takes samples at a fixed point in the river cross-section, although depth-proportional sampling is possible (Eads and Thomas, 1983). During deployment, EWI sampling may be conducted to ensure the representativeness of the discrete or depth-integrated sample. Finally, the intake should be faced upstream (Navratil *et al.* 2011). However, debris fouling and the potential for the purge cycle to be compromised against strong flow often leads to the intake being fixed perpendicular to the flow direction.

Discrete samples collected using automatic samplers have been shown to be comparable with those derived using manual sampling methods (Graczyk *et al.* 2000). However, they operate best in fine grained fluvial environments due to the samplers' inability to collect samples isokinetically (Lewis and Eads, 2008). Where sand-sized material is in transport, the particle size distribution and amount of sediment collected may be compromised (Bent *et al.* 2001).

Time-Integrating

Various time-integrating devices have been designed and used for monitoring purposes (Vanoni, 2006). A popular device is that designed by Phillips *et al.* (2000). It was originally developed to trap sediment through principles of sedimentation to be used for the assessment of physical, geochemical and magnetic properties of transported material in lowland rivers dominated by very-fine suspended sediment (e.g. Phillips *et al.* 2000, Russell *et al.* 2000). If deployed appropriately, the device is subject to the full range of flow conditions over the sampling period, providing a continuous record of suspended sediment flux, which may be representative of all events (Walling, 2005). The device has been used in a variety of fluvial environments for sediment source ascription studies (e.g. Collins *et al.* 2010, Fox and Papanicolaou, 2007, Fukuyama *et al.* 2010) and to assess sediment fluxes (e.g. Schindler Wildhaber *et al.* 2012). The device has also been subject to modifications for optimal operation in upland catchments (Figure 3; Perks *et al.* 2013) and arctic fluvial systems (McDonald *et al.* 2010).

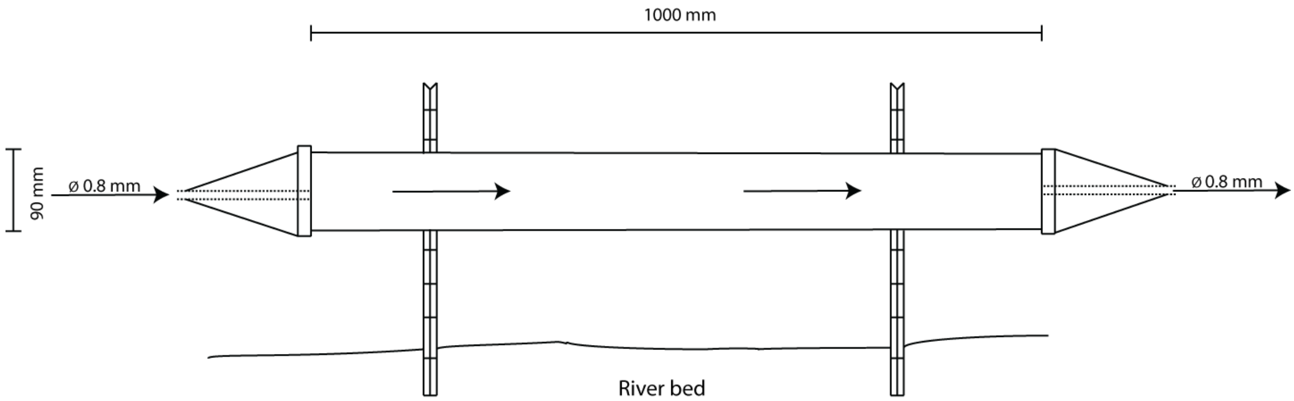

Figure 3: Schematic of a time-integrating mass-flux sampler (after Perks et al. 2013)

During deployment, the time-integrating sampler should be installed along a straight river reach with the inlet facing upstream. The device may sample a fixed position in the cross section (e.g. Perks *et al.* 2013, Schindler Wildhaber *et al.* 2012) or may have a variable sampling height (e.g. McDonald *et al.* 2010). The sampler is often left in-situ for a prolonged period (e.g. 30 days) to capture a sufficient mass of sediment for subsequent analysis. At the end of the sampling period, the device is removed from the river and the fine sediment is collected in sufficiently large containers to store the entire sediment-aqueous mix from within the sampler. The sampler should be rinsed and relocated with the samples taken to the laboratory for analysis.

Conclusion

Suspended sediment sampling methods can be categorised into: (1) manual sampling approaches capable of capturing a mass of material which is representative of the sediment flux; (2) devices capable of collecting discrete samples which can be passive or intelligently controlled to sample during events of interest; and (3) devices which are capable of collecting material which is potentially representative of the ambient flux over the entire monitoring period. Devices falling under (1) (i.e. manual samplers) require the presence of a field operative; largely precluding their applicability for studies interested in the dynamic nature of suspended sediment. Devices within group (2) (i.e. passive and pump samplers) are capable of collecting representative samples when the apparatus is appropriately located. They may also be configured to capture a sufficient mass of material for accurate analysis of, for example trace quantities of bound substances. Devices within group (3) (i.e. time-integrating devices) provide the potential means of overcoming the lack of temporal integration associated with (1) and provide a composite sample for analysis. However, further research is required to ensure that fully representative samples are collected using these devices. Each of these approaches may be used very effectively in combination (e.g. Perks *et al. 2013*). Although ultimately, a balanced decision based on the sample and data requirements, resources available and conditions of deployment must be made as to the most suitable approach and method(s) to adopt.

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